Multi-Facility TMA: Fully Dependent TMA Analysis

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1. Introduction

This report presents an analysis of the application of the Traffic Management Advisor (TMA) component of the Center-TRACON Automation System (CTAS) to complex airspace. Operational and system-level issues of Multi-center TMA (McTMA) are studied in application to the Philadelphia terminal area.

This document provides a generic analysis of McTMA issues. Many of the issues that are discussed are presented in the context of the Philadelphia operation. However, the same issues apply to other airports and environments within complex airspace as well. We have discussed some issues in the context of other airports - New York, in particular - in this document.

This document is a final version of the analysis of Fully Dependent McTMA. An Operational Concept is presented, as well as a discussion of algorithm and adaptation changes required for McTMA. Note that these elements of the document have not been updated since the draft version of this document was released. Additional analyses of the use of Tower En-Route Control procedures, and complex airspace issues have been added to this version of the document.

2. Background

The TMA portion of CTAS generates schedules for aircraft arriving at a Terminal Radar Approach Control (TRACON) facility. To this point in time, the system has been applied only to terminal areas that are entirely surrounded by a single Air Route Traffic Control Center (ARTCC). However, the potential benefit of TMA application in a multi-ARTCC environment could be even greater than the single ARTCC case.

In a single ARTCC environment, a single ARTCC Traffic Management Coordinator (TMC) has the entire picture of arrivals to the terminal area. The TMC can formulate a timely and consistent plan to meet the acceptance rate assigned by the TRACON - allowing for smooth and efficient flow management.

In a multi-ARTCC environment, however, multiple TMCs at multiple ARTCCs are involved in flow management. Each ARTCC TMC has only part of the arrival picture; the TRACON TMC is the first person in the arrival flow management progression to have the full arrival picture. Because numerous “short-hop” flights are an unpredictable element of an arrival rush, flow management is further complicated, leaving the TMC without the ability to accurately visualize arrival demand. By necessity, flow management becomes reactive.

An example of this problem can be seen at the PHL TRACON. Aircraft are allowed to flow into the TRACON until it is overloaded. At that point, the PHL TMC shuts off the flow from the ARTCCs. Once the situation in the TRACON is under control, the flow is resumed from the ARTCCs. However, the decision to resume the flow is difficult to make accurately, and it is often very difficult for the ARTCC controllers to efficiently vector aircraft out of holding patterns. This reactive mode of traffic management creates significant inefficiencies in the arrival flow.

TMA is the most promising solution to this problem. The TMA system receives flight plans for both active and proposed flights, as well as track data for active flights. Estimated Times of Arrival (ETAs) are generated for all arrival aircraft, including proposed flights. With the display of these ETAs on the TMA timelines, the TMCs at the TRACON and all involved ARTCCs will be able to see the arrival demand and formulate a smooth and efficient flow management plan.

NASA is evaluating three concepts for McTMA which use either miles-in-trail restrictions, metering or both. The Advanced Collaboration concept uses only miles-in-trail restrictions to conduct flow management. The TMA functions are used to assist in determining the best set of miles-in-trail restrictions to use. In the Transition to Metering concept, miles-in-trail restrictions are used in one ARTCC, and time-based metering is used in the other.

In the Fully Dependent McTMA concept, both ARTCCs use time-based metering for arrival flow management. It is expected that this concept will provide the most efficient management of arrival traffic flow. This document provides an analysis of issues associated with the design, implementation and operation of the Fully Dependent McTMA concept.

2.1. Operational Issues

The primary issues in the design of the operational concept for fully dependent time-based metering in McTMA are the coordinated planning of traffic management initiatives between facilities and coordinated re-planning to address unexpected events. Additional issues exist due to the complex nature of the airspace surrounding the PHL terminal area.

2.1.1. Planning Traffic Management Restrictions

The Fully Dependent McTMA concept uses time-based metering in both ZNY and ZDC ARTCCs. The use of time-based metering allows accurate planning and regulation of the arrival traffic flow. However, this planning process must be conducted pro-actively and must include coordination and collaboration between the TMCs at PHL, ZNY and ZDC for time-based metering to be effective.

In the case of Single Center TMA, a single ARTCC TMC can make autonomous decisions regarding:

- the time to start and stop metering,
- the combination of TMA restrictions to be used to meet the AAR identified by the TRACON TMC,
- the release of internal departure flights, and
- other flow management measures used to balance workload between ARTCC sectors

However, in the case of McTMA, all of these decisions are subject to coordination and negotiation between two ARTCC TMCs.

Although the use of time-based metering is expected to provide the most efficient management of arrival flow, significant coordination between ARTCCs may be required because of the dependency between the arrival schedules of each ARTCC. If a scheduled arrival fix time is changed for an aircraft arriving from one ARTCC, the potential exists for a change in the scheduled arrival fix time for all other aircraft arriving after that aircraft from either ARTCC. Thus, a TMC in one ARTCC could change the displayed arrival fix time on a sector controller's scope in a different ARTCC. This must be avoided through procedures and coordination. It is expected that some modifications to McTMA will also be required.

However, use of TMA at ZFW has shown that rescheduling frozen flights is only required infrequently. Normal operating procedures generally do not include the rescheduling of frozen flights. Thus, this coordination between ARTCCs, although significant and time-consuming, may occur only in rare circumstances.

2.1.2. Handling Unexpected Events

Although the basic planning of time-based arrival flow management is expected to require negotiation, sufficient lead-time will be available to complete the coordination. However, the occurrence of unexpected events will make the coordination process more difficult. Some of the unexpected events that may occur are described below. Each of these types of unexpected events, and others, cause the need to re-evaluate the time-based metering plan. In many cases, changes will be necessary, even to frozen meter fix times.

TRACON Overload

One of the problems that currently occurs at PHL is TRACON overload. Although we expect that time-based metering will significantly reduce the occurrence of this problem, it may still occur under particular circumstances. For example, if some flights are scheduled to use runway 17 or 35, but the pilots request one of the longer runways, additional delay may build up in the TRACON. If the delay that builds up in the TRACON exceeds the maximum TRACON delay capacity, it is likely that the flow from the ARTCC will be shut-off.

Once the flow has been shut off, the three TMCs must coordinate to determine the time at which the flow should be resumed, and the flow management restrictions that should be used to regulate the flow. Since many of the flights that remain in the ARTCC airspace will be in holding patterns, it is difficult to predict the flow rates that will result when flow is resumed. It may not be appropriate to attempt to resume time-based metering in such a situation, as an increase in workload will result.

Excess TRACON Capacity

On the opposite end of the spectrum from TRACON overload is the existence of excess TRACON capacity. Excess TRACON capacity may occur dynamically if additional flights are assigned to land on a reliever runway than anticipated. To avoid the loss of arrival slots when flights are being delay in the ARTCC environment, changes to the arrival flow plan are required. However, such changes must be coordinated between facilities and may result in frozen meter fix times being changed on sector controller's scopes.

Configuration Changes

When changes in the wind and/or weather conditions are significant enough to require an airport configuration change, rescheduling frozen flights is required. Generally, some arrival slots are lost when a configuration change occurs, due to the need to change the traffic patterns and allow flights to clear the runways from the previous configuration. If the configuration change occurs during an arrival rush, a brief flow shut-off may be required, as a result of the lost arrival slots. Since the flow shut-off, if required, will only be transitory, it may still be possible to resume time-based metering. However, this will require that a new flow management plan be coordinated between the three TMCs quickly, so that new frozen meter fix times can be given to the sector controllers.

Pops-Ups

Pop-ups are airborne flights that are unknown to the ATC system until the pilot calls a controller and requests a landing slot at PHL. Because the flight was unknown to the ATC system before the

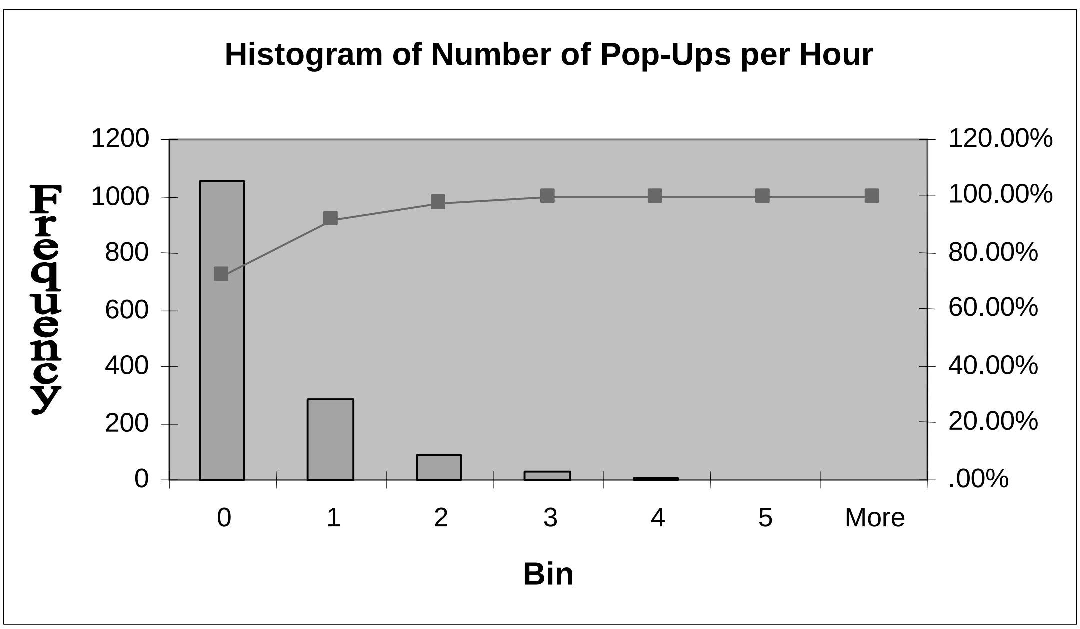

Figure 1 Histogram of Number of Pop-Ups per Hour

pilot calls, the PHL flow management plan does not include a slot for the flight. If the pilot does not call until the flight is close to the PHL arrival fixes, the slot for the pop-up flight may compete with slots for other frozen flights. Thus, to schedule a slot for the pop-up flight, frozen meter fix times for other flights would have to be changed, including flights in other sectors. While this may be necessary and appropriate in the sector that the pop-up flight is in, changing frozen meter fix times generally increases workload and should be avoided.

2.1.3. Limited TRACON Delay Capacity

Significantly less airspace is dedicated to the PHL approach control than to other approach controls in less congested parts of the country's airspace. The diagram below shows that the distance between the airport and the arrival fixes at PHL ranges from 24 nautical miles to 31

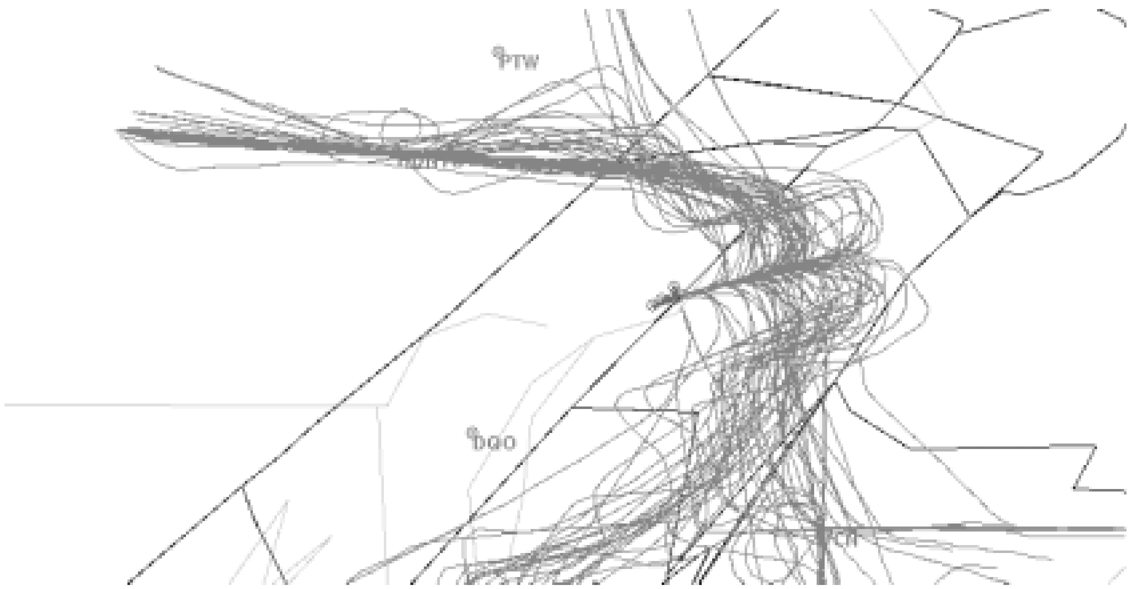

Figure 2 Due to the proximity of other terminal areas, a relatively small amount of airspace has been allocted to the PHL TRACON

nautical miles, whereas the distance at DFW is 42 miles.

While this issue is not directly related to the multi-facility issues of McTMA, it does increase the difficulty of successful flow management for PHL. The lower amount of airspace available in the TRACON for delaying and vectoring flights increases the likelihood that the TRACON will be overloaded. Thus, flow management must be conducted more accurately to avoid shut-off of the flow by the TRACON. This exacerbates the multi-facility flow management issues.

2.1.4. Complex Airspace

Other issues exist in the effect of airspace characteristics on the use of time-based metering itself. For example, in less congested airspace environments, it is less likely that arrival flights will be required to deviate to avoid conflicting flows of traffic. In the PHL arrival environment, crossing flows exist for the New York and Washington, D.C. area airports. These crossing flows can cause the need for miles-in-trail restrictions on PHL arrivals. These restrictions are not directly associated with PHL arrival volume, but are implemented to reduce the complexity and workload in the en-route sector in which the flows cross. However, these restrictions have a direct impact on the PHL arrival flow. Extra delay is caused by these restrictions that may cause flights to miss assigned meter fix times if the extra delay is not modeled.

More detail on these issues is provided in Section 6, Complex Airspace Analyses, on page 30.

2.2. CTAS System Issues

The existence of multiple ATM jurisdictions in close proximity to each other in the Northeast Corridor serves to distribute the workload of controlling the traffic in this area. The high number of major airports within this area results in Approach Control facilities that blanket the lower altitude regions of the entire airspace between Washington, DC and Boston.

However, this will create a significant challenge to the development and introduction of AATT tools in this region. The general view that has been taken of ATC automation tool development includes the following two simplifying assumptions:

1. Operational traffic management decisions for aircraft in the same phase of flight can be addressed by the same instance of a decision support tool.
2. The operational traffic management issues that affect different phases of flight can be addressed by separate decision support tools.

As an example of the first assumption, consider the airspace around Denver. The Denver TRACON airspace is entirely surrounded by Denver ARTCC airspace. All arrival aircraft that will enter Denver TRACON are controlled by Denver ARTCC and can be considered in the ARTCC's traffic management plan that is developed to control arrivals into Denver TRACON. In the case of CTAS, a single TMA system can receive track and flight plan data from the Denver ARTCC Host computer and have all the information necessary to schedule and manage arrivals into Denver TRACON.

In the Northeast Corridor airspace environment (as well as in other locations around the country) this is not the case. New York TRACON, for example, adjoins the airspace of three different ARTCCs: New York ARTCC, Boston ARTCC and Washington ARTCC. It is not possible for any of these ARTCC facilities to provide complete management of the flow into New York TRACON in today's NAS architecture. The necessary information for all arrivals destined for New York TRACON is not available at any one ARTCC location. An architecture (both operational concept and system architecture) must be developed for CTAS that allows management of flow in a multi-facility environment.

The second simplifying assumption is that the operational traffic management issues that affect different phases of flight can be addressed by separate decision support tools. For example, the CTAS system has been created for arrival traffic management, the URET and UPR systems have been created for en-route decision support, the DSP, DSEDM, and EDP programs have been initiated (and terminated, in some cases) for departure management, and the SMA program has been created for surface traffic management.

However, in the Northeast Corridor, the operational traffic management problems that impact aircraft in one phase of flight are often caused by aircraft in a different phase of flight. Aircraft that are in the en-route phase of flight must be vectored to provide space for departure aircraft. Arrivals must be vectored around departures. Arrival aircraft are often required to descend much earlier than desirable to allow en-route traffic to pass above. At this point, the impact that these issues will have on the operation of CTAS at PHL is unknown. Assessing the impact of these issues will be a topic of analysis in this effort. The results of this analysis will be reported in the Final version of this document.

Because of the nature of the Northeast Corridor airspace environment new requirements exist for ATC automation systems such as CTAS. Some of these new requirements have been identified in previous efforts, but many others will be identified through NASA's current MC-TMA research.

We expect that many of these requirements will pertain to the fact that multiple ATM jurisdictions exist in close proximity to each other. It is essential to the CTAS program that an architecture be established that will allow rapid expansion of capabilities once the system is introduced to the Northeast Corridor environment, to be able to satisfy the new requirements.

The approach that is currently being considered by the CTAS program, the virtual single center CTAS system, may require an independent CTAS system to operate for each major arrival Approach Control for which CTAS will provide schedules and advisories. However, these independent CTAS systems will not be able to generate displays of demand, schedules and advisories that depend on demand, schedules and actions from another CTAS system. This will allow CTAS to operate in the Northeast Corridor, but it will not address the interaction between the many ATM jurisdictions that exist and cooperate in the Northeast Corridor area.

For example, the management of the arrival flow for New York by CTAS may be dependent on the flow through sector 48 in Cleveland ARTCC airspace. It may be desirable to compute and display CTAS ETAs at the sector 48 boundary, or to place the CTAS outer fix arc in sector 48. However, there are many flights that fly through sector 48 that are not destined for a New York area airport. In the same stream as New York arrivals, we expect to find many Boston arrivals, as well as many other New England area airports. There may be different outer arc metering needs for the Boston flow that must be considered in the flow management of sector 48 traffic. However, some CTAS architectures will not support this approach.

The airspace environments surrounding both Denver and Dallas/Ft. Worth, the two CTAS prototype development sites, have a number of characteristics that do not exist in the Northeast Corridor area. For example, both the Denver and DFW terminal areas are the only major terminal areas within the airspace of the ARTCC in which they exist. In both of these cases, the terminal areas are located near the middle of the ARTCC airspace, so the entire descent profile for arrival aircraft is conducted within the destination ARTCC. Further, the ARTCC sectors have been designed to separate the arrival and departure flows from each other, and from overflight flows.

These characteristics have allowed the current CTAS architecture to model the ARTCC and TRACON as one single entity. In the New York area, however, there are multiple ARTCCs feeding a single TRACON. The single entity approach does not work in this situation. There will be multiple Host data feeds which must be consistent with the adaptation for that ARTCC. Procedures must be defined for supporting key CTAS computations, such as generating estimated times of arrival (ETAs). Would the CTAS at each of these ARTCCs need to replicate a set of adaptation data for the New York TRACON? How would the scheduling process be integrated between these CTAS installations at each adjacent ARTCC?

Many of these problems could be solved with minor modifications, but some of them will require significant architecture changes. Potential solutions to these problems that will be analyzed in the final draft of this document are described in section 5. Fully Dependent TMA System Changes.

3. Fully Dependent TMA Operational Concept

The primary issues in the design of the operational concept for fully dependent time-based metering in McTMA are the coordinated planning of traffic management initiatives between facilities and coordinated re-planning to address unexpected events.

The TMCs at ZNY, ZDC and PHL use the presentation of flight position, ETAs and aggregate demand on the TGUI and PGUI to assess the need for traffic management restrictions. This process is conducted on a continual basis by the TMCs through analysis of the TMA displays and telephone communication amongst themselves and with the Command Center.

3.1. Flow Management Planning

The PHL TMC determines the current arrival capacity of the airport, and the arrival capacity predicted for the next two or more hours. This arrival capacity is determined through evaluation of current and predicted weather conditions, airport equipment status, and predicted departure demand (either from historical data, or another decision support tool). The design of PHL airport configurations and operational procedures allow arrival and departure capacity to be traded-off. Through the use of accurate time-based metering, this trade-off can be used more efficiently and effectively. Thus, the arrival capacity determined by the PHL TMC may vary over time, even with constant weather conditions.

The arrival capacity is communicated to the other TMCs and the Command Center so that a common understanding of any excess demand exists. Through the use of the TGUI load graphs, the TMCs identify any delay that may be backing-up from the TRACON. Delay could back-up from the TRACON if flights do not land at the full level of predicted arrival capacity that was used to plan the arrival flow. It may be necessary to further reduce the flow from the ARTCCs temporarily to reduce the excess demand that exists in the TRACON if delay is building up. It is expected that the PHL TMC will be primarily responsible for identifying the need for flow management restrictions, and coordinating that need with the ARTCC TMCs.

Once the TMCs have determined that the flow must be reduced, the necessary flow parameters are entered into the TMA system. These parameters include the airport acceptance rate (AAR), runway acceptance rates (RARs), final approach separation matrix, arrival fix miles-in-trail restrictions and any blocked intervals required to temporarily reduce the flow. The TMC enters the appropriate parameters to manage the arrival operation between 45 minutes and 90 minutes ahead of the actual arrivals. This allows sufficient time for the schedules to be generated and coordinated before being displayed to the controllers for implementation. The scheduled times for arrivals are generally frozen when they get within 19 minutes of the arrival fix.

One of the facilities involved in the flow management process is designated the responsibility of entering scheduling parameters into the TMA system. It is expected that the ZNY TMU will make these entries, as PHL approach control is associated with the ZNY host computer. We assume this to be the case in the remainder of this case study scenario.

The parameters entered by the ZNY TMC appear on all other TMA displays, including those at the ZDC ARTCC, PHL TRACON and the Command Center, if available. The availability of a TMA display at the Command Center would enhance the collaborative planning between ATC facilities. In addition to the scheduling parameters, all TMA displays show the schedule that has been developed by the TMA. This schedule assigns airport and arrival fix crossing times to flights to make efficient use of airport arrival capacity and to equitably distribute delay among flights.

However, the initial TMA schedule does not necessarily distribute workload between sectors and controllers equitably. Further, the TMA schedules do not consider the sector workload due to non-PHL arrival flights. As a result, it may be necessary to adjust the scheduling parameters to properly balance sector workload, while maintaining arrival efficiency. The required flow plan modifications are determined by the TMCs in the form of additional miles-in-trail restrictions to be applied at some of the arrival fixes. This approach to modifying the TMA schedule can be used to increase the delay in some sectors and reduce the delay in others to more equitably distribute the workload. However, the TMA will continue to generate schedules that make the most efficient use possible of airport arrival capacity. Even though miles-in-trail restrictions are used in this situation, the end result remains a TMA schedule that is implemented through time-based metering.

Note that there are drawbacks to this approach. As we have identified through other studies of the application of McTMA to the PHL arrival environment, it is difficult to use miles-in-trail restrictions to accurately manage the flow due to the flow characteristics of PHL arrivals. As an alternative, TMA algorithm modifications could be made to provide a more direct means of increasing or decreasing delay over specific arrival fixes. In all cases, TMA schedules to use the airport capacity as efficiently as possible, given the TMC-entered restrictions. TMCs can evaluate whether or not the restrictions they have entered are too constraining using the TGUI load graphs. Further investigation must be conducted to evaluate the need for alternatives to miles-in-trail restrictions for this application. Two alternatives that exist are the use of a weighting factor to equitably distribute a 'weighted' delay between flights, or the use of a constant TMC-entered additional delay to be applied to all flights that arrival over a TMC-specified arrival fix during a TMC-selectable time interval.

The specific operational procedures through which the TMCs negotiate schedule modifications are yet to be determined. It is expected that simulation exercises will provide many answers in the attempt to identify these procedures. A clear and direct motivation to cooperate is needed, but has not yet been identified. Such motivation can only be created if it is in the best interest of one facility to cooperate with and help the other facilities. Without such motivation, it is expected that each facility will primarily attend to its own needs, and be unwilling to increase delay to reduce the workload of another facility's sector. In the absence of effective collaboration, it may be necessary for the Command Center to become directly involved in the establishment of scheduling parameters.

In either case - whether the ARTCC TMCs negotiate schedule modifications between themselves or if the Command Center must get involved - a Sector Workload measure may be useful. A Sector Workload measure could be used as an unbiased measure with which to determine the need for and severity of schedule modification. The ARTCC TMCs could use this measure to settle the question of workload distribution between sectors, and to evaluate the effectiveness of schedule modifications in achieving an equitable distribution of workload. If the Command Center is involved, the controller at the Command Center can use the Sector Workload measure to evaluate the need for schedule modifications. Note that the Sector Workload measure would have to consider sector workload due to non-PHL arrival traffic.

The issue of inter-ARTCC negotiation procedures will be studied further for the Final Fully Dependent TMA Analysis Report through interviews with operational experts.

After the schedule has been modified to manage flow and workload, the scheduled arrival fix crossing times are broadcast from the TMA to the controller sector displays. The implementation of time-based metering by the controller in the McTMA case follows the same procedures as the Single Center TMA case. Controllers give speed and descent clearances and use vectors to control flights to cross the arrival fix at the assigned time. If necessary, controllers can swap the assigned slots for flights that have the same engine type. As stated previously, the complexity and congestion of the Northeast airspace may cause unavoidable delay. This may in turn cause some flights to miss their assigned arrival fix crossing time. The frequency of occurrence of this phenomenon and the severity of impact on the overall arrival situation will be the subject of further analysis.

As the time-based metering plan is being implemented, TMCs at PHL monitor the performance in the TRACON, and evaluate the need for re-planning of the arrival schedule. This is discussed further below.

3.2. Internal Departures

The Northeast Corridor environment includes many regional operators and short-hop flights. As a result, there are many arrival flights at PHL that originate from airports within the ZNY or ZDC boundaries. One of the duties of TMCs at both ZNY and ZDC is to release these internal departure flights, for PHL and other major airports. Just like the current operation, these internal departures must be handled one-by-one in TMA. TMA provides additional features to simplify the departure release process, but the process is also complicated by the multi-facility nature of the PHL arrival environment.

Flight Plans for all known internal departure flights that are destined for PHL are received by the McTMA system. This includes flights from ZNY and ZDC (at least, maybe others). Estimated times of arrival are generated for these internal departures and displayed on the TGUI. These internal departures are identified on the TMA display through time-sharing of the departure airport identifier with the aircraft id. By default, these flights are not included in the TMA schedule until a TMC makes an entry indicating that the flight is ready to go.

Operationally, the TMC manages the release of internal departures to control workload in the affected sectors and to control the demand on PHL arrival capacity. The TMC often must evaluate the specific slot that the internal departure will use in the en-route flow of traffic to determine the workload that will be imposed on affected sectors. Currently, the TMCs use both the TMU see-all PVD and the ASD display to evaluate these issues.

No new issues are introduced by the multi-facility nature of TMA for PHL in regard to managing sector workload in departure release planning. Each TMC is responsible for identifying the impact of internal departures on the sectors in their facility. However, managing the demand on the PHL airport must be coordinated between the two facilities.

Generally, when an internal departure is ready to be assigned a departure slot, a tower controller at the departure airport calls the TMU at the appropriate ARTCC facility. The tower controller identifies the flight that is ready to go, and provides the earliest possible wheels-up time to the TMC. Using knowledge of the flight time between the departure airport and PHL, the TMC evaluates the demand at PHL and the average delays that are being experienced at the internal departure flight's time of arrival. The TMC also evaluates the demand in the sectors that the flight will traverse to evaluate the sector workload. Based on these evaluations, the TMC assigns a departure release time to the flight and gives the time to the tower controller.

With TMA, the assignment of a departure release time is conducted through TMA scheduling. In the multi-facility case, the scheduling of internal departure flights will also abide by the additional miles-in-trail restrictions or other prioritization that is used to equitably balance workload between facilities. Thus, it is not necessary for TMCs in the two ARTCC facilities to manually coordinate the assignment of a departure release time.

Since the TMA scheduling of internal departures adheres to facility workload balancing priorities, sector workload for internal departures is considered indirectly. In some cases, the TMC may need to manually assign a departure release time due to considerations that are not included in the TMA scheduling process.

To avoid the possibility of changing frozen meter fix times, internal departures are scheduled 'around' the assigned meter fix times for frozen flights. Generally, the internal departure flight is scheduled behind all frozen flights, unless there are open arrival slots. If this results in unacceptably high delay for the flight, the TMC can coordinate with the appropriate area supervisor in the TMC's facility to swap the meter fix slots of some flights to reduce the flight's delay. Using this procedure, the TMC leaves the departure flight's assigned meter fix time as scheduled by TMA. However, the implementing sector controller is informed that the internal departure will be released out of sequence. When the sector controller receives the internal departure flight, he or she may swap the meter fix time assigned to the departure flight with another flight. In this procedure, the meter list does not change. Thus, rippling of the meter list at all sector positions is avoided.

3.3. Handling Unplanned Events

The procedures described above are designed to avoid the need to change frozen meter fix times. However, when unexpected events occur, it may not be possible to avoid meter list rippling. This section describes four specific unplanned events that are expected to occur. Where possible, procedures to deal with the situation and avoid meter list rippling have been identified. Because of their nature, it is not possible to identify all possible unplanned events. However, it is expected that the procedures to address these four events will provide a framework for procedures and techniques to handle other types of unplanned events.

3.3.1. TRACON Overload

Two different approaches to TRACON Overload situations have been identified. The nominal approach assumes the current level of TMA functionality. The alternate approach proposes new TMA capabilities to improve system performance in TRACON Overload situations.

Nominal Approach

The TMA displays provide tools to assist the TMCs in identifying and predicting the occurrence of TRACON overload. The load graphs are used by the TMC to evaluate the arrival demand of flights that are in the TRACON airspace and the amount of average airborne delay that must be absorbed by flights before landing. As the average delay in the TRACON increases toward the maximum TRACON delay capacity, TRACON overload becomes likely. When a TMC identifies a delay build-up in the TRACON, the TMC communicates the possible problem to the other TMCs so that all TMCs at ZNY, ZDC and PHL are aware of the situation.

When the shut-off decision is made, sector controllers assign holding patterns to flights in ARTCC sectors to wait for the flow into the TRACON to be resumed. We expect that recovery from a TRACON shut-off will not be possible with time-based metering due to the number of clearances and workload of vectoring flights out of a holding pattern. Thus, the flow management approach will revert to miles-in-trail restrictions.

TMA provides tools to support the flow-resumption decision. The best method by which TMCs (or PHL controllers or supervisors) can use TMA to determine when to resume the flow from the ARTCCs is the load graphs. A shut-off will occur when the number of aircraft in the TRACON airspace exceeds the TRACON capacity. At this point, the load graphs will show that the demand at the threshold during the next 15 to 30 minutes exceeds the airport arrival capacity. This demand will include both the aircraft already within the TRACON, and the aircraft that are holding at the arrival fixes. As the flights already in the TRACON continue through the pattern to land, the demand shown on the load graphs in the next 15 to 20 minutes will reduce. The demand shown beyond 15 to 20 minutes will remain essentially constant while the aircraft outside the TRACON remain in a holding pattern.

Thus, the TMC should be watching the load graphs to see when the demand in the next 15 minutes meets or dips below the AAR. As soon as that point is reached, the flow should be resumed with appropriate miles-in-trail to keep the flow from overloading the TRACON again. TMA tools can be used to determine these miles-in-trail restrictions.

Alternate Approach

An alternate approach has been devised that relies on the addition of new TMA features that may help avoid TRACON shut-off. The TMA system can continually monitor the TRACON operation to assess the build-up of delay in the TRACON. The time-based metering plan developed by the TMA system automatically assigns some of the delay that must be absorbed by each flight to the TRACON. In other words, if flights meet their meter fix times exactly, some vectoring and delay will still be required for those flights in the TRACON. The amount of delay that TMA defers to the TRACON is controllable by a TMA parameter. Generally, this parameter is set at four or five minutes of TRACON delay. However, TMA can monitor in real time the actual amount of delay that flights are absorbing in the TRACON.

If delay builds up in the TRACON and it is not corrected, TRACON shut-off will result. However, if the delay builds up slowly over an arrival rush, it may be possible for TMA to schedule some empty slots later in the arrival stream to reduce the TRACON delay. The slots would be scheduled later in the time-based metering plan to avoid changing frozen times.

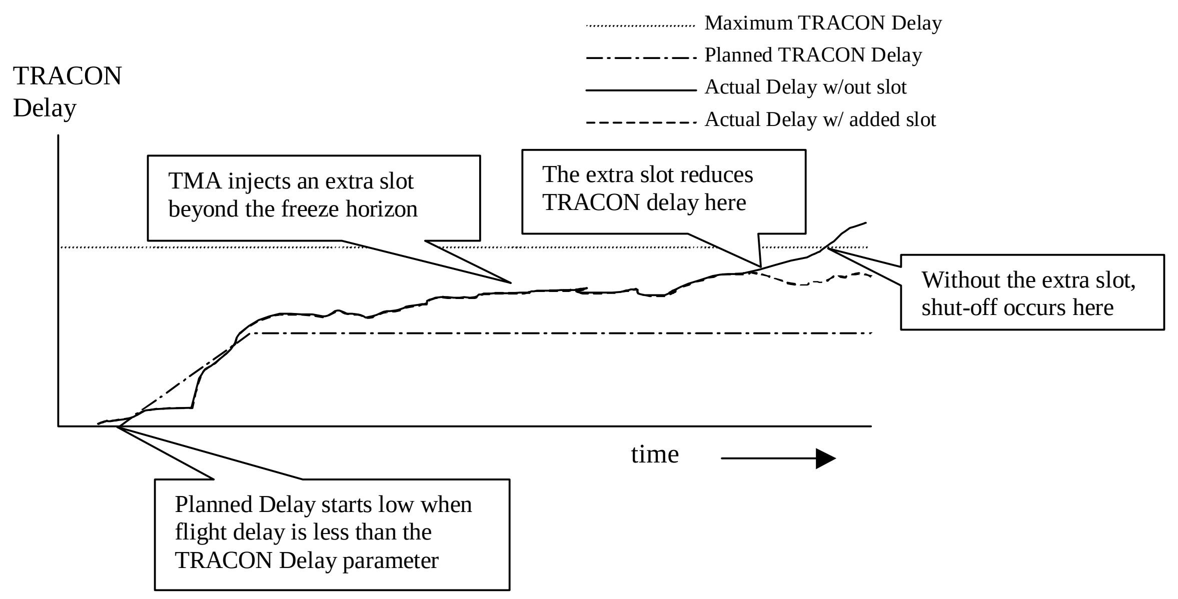

Figure 3 Adaptive TMA Scheduling may allow TRACON Overload to be Avoided

This approach could be implemented so that it occurs automatically, or it may be more appropriate to provide a suggestion to the TMC to reduce the TRACON delay by adding an empty slot somewhere in the arrival flow. These alternatives will be analyzed through interviews with operational experts and reported in the final version of this document.

3.3.2. Excess TRACON capacity

When the TRACON operation occurs more efficiently than planned by TMA, excess TRACON capacity may result. In this case, the actual TRACON delay is less than the TRACON delay planned by TMA. However, arrival slots will not be lost unless the actual TRACON delay becomes less than zero, indicating that flights would have to be sped up to make their arrival slots. Since the TMA TRACON Delay parameter is usually set to four or five minutes, the actual TRACON delay must reduce significantly before arrival slots are lost.

Nominal Approach

The TMCs at PHL monitor the TRACON situation in an arrival rush by evaluating the length of the final. If there are not enough aircraft on final approach, then an appropriate reservoir of aircraft doesn't exist in the TRACON as it should. The PHL TMC notifies the TMCs at ZNY and ZDC. The first step of the ARTCC TMCs is to look for flights that are readily available to be handed off to the TRACON. In general, the TMC looks for opportunities to increase the flow into the TRACON without changing frozen times for flights.

For example, if flights are holding at any of the arrival fixes, the TMCs can direct that some or all of the holding flights should be given clearances to exit the holding pattern and continue on to the airport. Second, if there is an arrival fix with a relatively light load of traffic, time-based metering can be cancelled over that fix so that no delay is imposed on those flights. This will allow additional flights to be added to the reservoir of flights in the TRACON, without having to change meter lists.

If it is not possible to find flights that are readily available to be handed off to the TRACON, then changes must be made to the time-based metering schedule. This will result in meter list rippling. Before these changes are made, the TMCs at PHL, ZNY and ZDC discuss the arrival situation together to attempt to determine the reason that the excess TRACON capacity exists. Has the airport acceptance rate increased? Is an additional runway in use? If there has been a change in the arrival situation, then those changes should be made in the TMA system (configuration change, AAR change, RAR change, etc.).

In an excess capacity situation, if no flights are holding at the arrival fixes and there are no other 'easy' means by which additional flights can be handed off to the TRACON, then metering should be discontinued. The TMCs then utilize the TMA load graph displays to determine if metering must be start again to regulate the flow. If the arrival rush is nearing an end, it may not be necessary to re-start metering. However, if the demand continues to exceed capacity, than metering will need to be re-started after the TRACON reservoir of flights has been re-filled. The TMCs work together to re-plan and coordinate the new time-based metering plan. The TMA load graphs and timelines are used to determine the appropriate time to start metering. Some TMCs may look at the load graph to find the time at which the necessary number of 'extra' flights will have been handed off to the TRACON to start metering then. Other TMCs may look at the timelines to find the time at which the required delay exceeds the TRACON Delay parameter. Through negotiation and coordination between the TMCs, the time to re-start metering is determined, the new metering times are sent out to the sector positions, and the first slot time to use for control is communicated to the controllers.

Alternate Approach

The alternate approach to handling excess TRACON capacity is analogous to the alternate approach for handling TRACON overload. This approach assumes the addition of adaptive scheduling capabilities in TMA, as described previously. In the case of excess TRACON capacity, the adaptive scheduling capabilities move up the assigned meter fix time for some flights to increase the pressure on the TRACON. To avoid changing frozen meter fix times, only flights that are beyond the TMA freeze horizon are moved up. Again, this approach only works when the actual TRACON delay is decreasing slowly, so that there is enough time for the flights that are moved up to have an impact on the TRACON flow before slots are actually lost.

This approach could be implemented in an automatic mode, such that TMA continually monitors the actual TRACON delay and changes assigned meter fix times appropriately. Or, this alternate approach could be implemented to provide suggestions to the TMCs to move up times or take other measures to increase the flow to the TRACON.

3.3.3. Configuration changes

The TMC at the TRACON continually monitors the weather conditions at the airport to evaluate the possible need for a configuration change. Often this evaluation is conducted in conjunction with the Tower Supervisor. Whenever possible, a configuration change is avoided when a busy arrival or departure rush is in progress. Significantly less workload and delay result from a configuration change when it is conducted at lower demand levels. However, the weather does not always allow a configuration change to occur at convenient times.

When the need for a configuration change is identified, the TRACON TMC notifies the ARTCC TMCs of the impending configuration change. If, by chance, it is possible to maintain the current McTMA operation, even as the actual airport configuration changes, the TMCs may decide to do so. This would only occur when the arrival acceptance rate to the new configuration is the same as the old configuration, and the configuration change can be conducted without more than a few lost slots.

In most cases, it is necessary to implement the configuration change in McTMA and reschedule the flow. The TMCs at the TRACON and ARTCCs will jointly discuss and determine the appropriate time to switch configurations, and the amount of gap that must be provided in the flow to allow the configuration change to take place. The configuration change is entered by one of the ARTCC TMCs, and the flow gap is entered as a blocked interval. The new scheduling parameters are all entered as early as they are known, so that meter fix times can be computed and distributed to the sector positions. Again, the determination of scheduling parameters involves negotiation between TMCs, and may require the use of an McTMA 'what-if' mode of scheduling. The McTMA schedule ensures that the flow from the ARTCC to the TRACON after the flow gap front-loads the TRACON for the new configuration.

At the sector position, it may be challenging to create a gap in the flow and then meet new meter fix time accurately. The flow gap may be sufficiently large that holding must be initiated to assign the necessary amount of delay. However, it is difficult to get flights out of holding patterns accurately. Hopefullly, the new meter fix times are presented to controllers early enough that an organized plan can be put in place to meet the meter fix times as accurately as possible. If not, the TMCs may be confronted with a TRACON Overload or Excess TRACON capacity situation after the configuration change. This would be dealt with as described above.

3.3.4. Pop-Ups

Pop-Up flights are handled in a manner similar to Internal Departure flights. If a pop-up flight needs to be scheduled into the arrival flow, attempts are made to avoid changing frozen meter fix times. This is done by scheduling the pop-up flight after frozen meter fix times. If this results in unreasonable delay, then the sector controller that is controlling the pop-up flight can swap that flight's slot with another flight's slot.

In general, pop-up flights are assigned a 'Fuel Advisory' delay so that they experience the same amount of delay, on average, as flights that were known to the system earlier. These delays are assigned to discourage operators from conducting their flights in a manner that creates inefficiency and inequity.

4. Fully Dependent TMA Requirements

4.1. TMA System Requirements

This section presents a synopsis of McTMA system level requirements. The requirements presented here have been developed through a review of the CTAS Build 2 System Specification and through the analysis conducted and presented in this document. These requirements are high-level requirements that are specific to multi-facility TMA issues.

Some of the requirements included in this section have been designed to address specific issues of complex airspace. For example, requirements are included below to allow modeling of miles-in-trail restrictions at sector boundaries in the generation of TMA schedules. However, we have not yet conducted the analysis to verify that the effect of miles-in-trail restrictions at sector boundaries is significant enough to warrant these requirements. Analysis of this issue will be conducted in the development of the final version of this document, and the need for these requirements will be re-evaluated.

4.1.1. Data Management

1. TMA shall receive surveillance data for all airborne aircraft that are within 200 nm of an adapted primary airport and that are destined for that airport, whenever such data is available. It is expected that such data will generally be available from ARTCC Host computers, TRACON ARTS computers, and the ETMS system. Data may not be available for flights in oceanic airspace, or in the airspace over some foreign countries.
2. TMA shall correlate the surveillance data received from different sources for the same airborne flight so that only one flight is recognized in CTAS for each airborne flight.
3. TMA shall assign each flight's meter fix as the meter fix that is closest to the flight's horizontal route.
4. TMA shall determine the set of allowable runways for the flight at the destination airport dependent on the meter fix and aircraft engine type.
5. TMA shall determine the coordination fix or horizontal position at which each flight crosses from one ARTCC to another.
6. TMA shall determine the positions along each flight's horizontal route and vertical profile that the flight exits one sector and enters another.
7. TMA shall allow the user to enter miles-in-trail restrictions that have been imposed at sector or ARTCC boundaries.

4.1.2. Generation of ETAs

8. TMA shall generate estimated times of arrival (ETA) for all airborne flights at the assigned meter fix and at all allowable runways at the destination airport.
9. TMA shall generate estimated times of arrival at all sector and ARTCC boundary crossing locations.

4.1.3. Generation of STAs

10. TMA shall schedule all flights for which track data has been received in the same manner as if those flights were in the airspace of the arrival ARTCC.

11. The earliest scheduled time of arrival (STA) that TMA generates for a flight shall be the earliest possible time of arrival at the airport runway considering any miles-in-trail restrictions that are imposed on the flight at the meter fix, sector boundaries or ARTCC boundaries.

12. TMA shall include all flights in each miles-in-trail stream in determining the earliest possible STA for a flight. This requirement is necessary because miles-in-trail restrictions at sector and ARTCC boundaries may include other flights that are not destined for the CTAS primary airport. In such cases, the existence of the overflight must be modeled because it may cause additional delay on the arrival flight.

4.1.4. Data Display

13. TMA shall be capable of displaying track data, ETAs and STAs for all flights for which track data has been received on any TMA Timeline Graphical User Interface (TGUI) or Planview GUI, regardless of the facility in which the display is installed.

4.2. TMA Functional Requirements

We assume in this section that the Fully Dependent Metering concept is implemented through an integrated TMA system that maintains a flight database for all ARTCCs that have airspace within 200 nm of the primary airport. However, we have attempted to avoid making any assumptions about the software and processing architecture that is used to implement this integrated system. So, the Fully Dependent Metering concept may use a single 'virtual' center. Or, two or more separate TMA systems that are interfaced to each other with *fully integrated* scheduling functions could be used to implement the Fully Dependent Metering concept. Additional discussion of software and processing architecture alternatives is presented in Section 5, Fully Dependent TMA System Changes, on page 24.

The two tables in this section present a function-by-function analysis of changes that are required to TMA capabilities for the Fully Dependent Metering concept. These tables follow the structure and approach used in the Task Order 16 study, conducted by System Resources Corporation, to facilitate comparison of the Fully Dependent Metering concept, with the two concepts presented in detail in that study.

Setup Parameter		*Impact of Fully Dependent McTMA Concept*
Name	**Panel**	
Airport	F1	Unchanged
Configuration	F1	Coordination required*
Airport Acceptance Rate	F1	Coordination required, as above
Runway Flow Rates	F1	Coordination required, as above
Separation Matrix and Buffer	F1	Coordination required, as above
TRACON Acceptance Rate	F1	Coordination required, as above

TRACON Delay	F1	Coordination required, as above
Gate and Meter Fix Acceptance Rates	F1	Coordination required, possible additional uses*
Stream Class Settings	F1	Coordination required, possible additional uses*
Show Scheduling Functions	F1	Unchanged
En-Route Miles-in-Trail	New	New*
Load Graph Settings	F2	Unchanged
Plot Settings (Load Graph)	F2	Additional data*
Current Display Format	F3	Unchanged
Proposed Flights	F4	Additional data*
Not On Timeline	F4	Unchanged
Traffic Count	F5	Additional data*
Delay Reporting Status	F6	Unchanged
Configuration Summary	F7	Unchanged
Popup Aux Data	F8	Unchanged
Timeline Setup	F9	Unchanged
Scheduling Options	Shift F10	Additional data*
Flight Plan Readout	F11	Unchanged
Rush Alert Configuration	F12	Unchanged
Blocked Scheduled Broadcast Configuration	Shift F12	Unchanged

* Detailed comments below

Configuration

The specification of the airport configuration in the Fully Dependent Metering concept is one of many TMA functions that causes the need to reschedule frozen flights, and/or may change the distribution of delay and workload between facilities. Other such TMA functions include Airport Acceptance Rate, Runway Flow Rates, Separation Matrix and Buffer, TRACON Acceptance Rate, TRACON Delay, Gate and Meter Fix Acceptance Rates and Stream Class Settings.

Because meter fix times for flights in other ARTCCs may occur when any of these functions are exercised, there must be coordination between TMCs when these functions are used. The coordination can be implemented procedurally, but it is more appropriate to implement some software changes to encourage and assist in the collaboration and coordination. The software changes could either provide a reminder to the TGUI user that makes a change to scheduling parameters through one of these functions, or, the software could require approval by a TMC from each of the facilities before the scheduling change is implemented.

Gate and Meter Fix Acceptance Rates

In addition to the functionality changes required to encourage collaboration and cooperation in setting scheduling parameters for the Gate and Meter Fix Acceptance Rates function, some functionality changes may be appropriate. These functionality changes would be designed to support the use of gate and meter fix acceptance rates to balance workload between sectors. The specific nature of these changes will be studied further in the preparation of the final version of this document.

Stream Class Settings

Some changes may be necessary to single gate free flow concepts to support multi-center workload distribution and other complex airspace issues. This will be the subject of further investigation in the preparation of the final version of this document.

En-Route Miles-in-Trail

New functions are required in McTMA to allow the specification of miles-in-trail restrictions to be applied in upstream en-route sectors. For example, sector 27 in ZNY handles arrivals to both IAD and PHL. The IAD arrival stream becomes sufficiently complex in sector 27 that miles-in-trail restrictions are placed on PHL arrivals to reduce the overall sector demand. To accurately manage the PHL arrival flow, these miles-in-trail restrictions must be explicitly modeled. To be modeled, they must be entered by a TMC. The new panel identified in the table above is designed to allow the TMC to enter all necessary en-route miles-in-trail restrictions.

Plot Settings (Load Graph)

The plot settings do not have an impact on the TMA scheduling process. So, there is no need for coordination in the use of load graphs and plot settings. However, additional load graph functionality may benefit the collaboration between facilities in the use of McTMA. The creation of a workload measure has been proposed above. An appropriate way to display the output of such a measure is on the load graphs. An additional plot setting would be added to allow the workload prediction measure to be plotted on the load graphs.

Proposed Flights

The Proposed Flights list will remain significantly unchanged. However, at least two different ARTCC TMUs will consult the Proposed Flights list to find flights that are still on the ground at an airport in their ARTCC airspace. Thus, an indication of the ARTCC that controls the airport from which the proposed flight is departing would assist the TMCs in filtering the flights of interest.

Traffic Count

Similarly, the Traffic Count feature will remain predominantly unchanged. However, additional data columns to indicate the amount of traffic coming from each ARTCC may benefit the coordination and collaboration between facilities.

Scheduling Options

Additional parameters may be added to the Scheduling Options panel to control the behavior of new McTMA scheduling functions.

For example, if TMA scheduling algorithms are enhanced to include workload prioritized scheduling, additional parameters may be necessary to control the operation of the new algorithm. In the case of workload prioritized scheduling, it may be appropriate to allow the TMC to set a maximum additional that can be imposed on any flight to allow workload prioritization.

As a second example, consider the adaptive rescheduling that has been proposed above to address TRACON Overload and Excess TRACON Capacity. Additional scheduling parameters may be appropriate to control whether the adaptive rescheduling occurs automatically, or as a suggestion to the TMC, and the level of deviation from planned TRACON Delay that triggers a TMA scheduling response.

Functionality	*Impact of Fully Dependent McTMA Concept*
Name	
Locate and Aircraft	Unchanged
Manual Rescheduling	Coordination required*
Reschedule Aircraft	Coordination required, as above
Broadcast	Coordination required, as above
Runway Change	Coordination required, as above
Allocate Runway	Unchanged
Metering Fix Change	Coordination required, as above
Proposed Meter Fix	Unchanged
Suspend Scheduling	Unchanged*
Resume Scheduling	Unchanged, see notes for Suspend Scheduling
Reset Aircraft	Unchanged, see notes for Suspend Scheduling
Priority Status	Coordination required*
Find Slot	Unchanged
Planned Separation of Two Aircraft	Unchanged
Blocked Intervals	Coordination required
Blocked Slots	Coordination required
Delay an Aircraft at a Satellite Airport	Limit to Controlling ARTCC*
Ground Delay	Limit to Controlling ARTCC, as above

* Detailed comments below

Manual Rescheduling

As described above, any TMA functions that may result in changing frozen meter fix times must be coordinated between all facilities involved. Such functions include Manual Rescheduling, Reschedule Aircraft, Broadcast, Runway Change, and Metering Fix Change. The same discussion that was presented above regarding TMA changes to encourage collaboration and coordination applies here as well. TMA functions could be changed to suggest coordination, or to enforce coordination by requiring approval from all TMCs involved before any schedule change is made.

Suspend Scheduling

It is assumed that the McTMA version of the Suspend Scheduling function does not automatically invoke a reschedule operation. A similar assumption is made for Resume Scheduling and Reset Aircraft functions. Thus, coordination is required when the rescheduling operation is conducted, but this is addressed by the paragraph preceding this one.

Priority Status

Due to the critical nature of designating a flight as a priority aircraft, no coordination will be enforced by the TMA system. TMCs must be trained to know that the Priority Status operation will take effect immediately, and that coordination has to be conducted after the fact.

Delay an Aircraft at a Satellite Airport

The McTMA functions to Delay an Aircraft at a Satellite Airport and perform a Ground Delay both apply to internal departures. The TMA version of the functionality must be changed to prohibit TMCs at one ARTCC from making changes to the internal departures of another ARTCC.

5. Fully Dependent TMA System Changes

This section describes changes to the TMA software system that are or may be required to support McTMA operations. The changes are organized into sections covering algorithms, system architecture and adaptation.

5.1. Algorithm Changes

Metering to fill rate

Single gate free flow capabilities have recently been added to TMA. This capability allows TMA to schedule flights through one arrival fix to use minimum miles-in-trail separation, or a specified miles-in-trail separation, while flights through other arrival fixes are scheduled 'around' the miles-in-trail stream. TMA first schedules the miles-in-trail stream, and then determines the amount of the overall arrival rate that is not used by the flights in the miles-in-trail stream. Flights from the other arrival fixes are then scheduled to meet this remaining arrival rate.

This capability may be useful in McTMA operations in numerous situations. For example, many Northeast Corridor terminal areas, including PHL, are close enough to the Atlantic coastline that there is little opportunity to control oceanic flights. Oceanic flights enter radar coverage only a short distance before crossing the coastline. In addition to the small amount of airspace to vector and control the flights, these flights often receive priority handling due to their potential for low fuel situations.

Another example is described below, in the paragraph titled Workload Prioritized Metering.

Changes may be necessary to the TMA single gate free flow capability to support these and other necessary McTMA operations. A more detailed evaluation of McTMA use of single gate free flow capabilities will be conducted in the preparation of the final version of this document. Any changes to single gate free flow that are required for McTMA operation will be included in the final version.

Modeling Miles-in-Trail Restrictions at Sector and ARTCC Boundaries

As described previously, miles-in-trail restrictions may be imposed on PHL arrival flights to manage en-route sector workload. These miles-in-trail restrictions may not be necessary to meet the PHL arrival acceptance rate. If the miles-in-trail restrictions are applied for management of en-route sector workload exclusively, then additional delay will be imposed on flights. TMA scheduling algorithms do not consider en-route miles-in-trail restrictions. As a result, flights may not be able to meet their scheduled meter fix time.

In order to correct this potential error, the effect of miles-in-trail restrictions at sector and ARTCC boundaries must be explicitly modeled. Undelayed arrival times must be computed at sector and ARTCC boundaries. Then, the miles-in-trail restrictions can be used to predict the earliest possible arrival time at the PHL meter fix, considering upstream miles-in-trail restrictions. With the earliest possible arrival time available, TMA scheduling can include this earliest possible meter fix arrival time as an additional constraint on the scheduling process. If a particular flight cannot get to the meter fix early enough, then that flight's slot can be given to another flight that is not subject to upstream miles-in-trail restrictions. In this manner, the slot will not be lost, which would be a possibility if the upstream miles-in-trail restrictions were not considered.

Note that the potential impact of upstream miles-in-trail restrictions is not known. Before we suggest that significant effort be undertaken to implement changes to address this potential issue, we will conduct an analysis to assess the potential impact of this issue. The results of the analysis and final recommendations will be included in the final version of this document.

Workload Prioritized Metering

As described previously, the negotiation process between ARTCCs to establish scheduling parameters may benefit from a workload measure. This workload measure could consider the number of flights to be handled in each sector, the delay that must be imposed on the flights in the sector, and other operations being conducted in the sector to determine the cognitive workload that is required from the controller to manage the situation.

Such a workload measure could be displayed on load graphs to provide TMCs with an unbiased measurement of the distribution of workload between sectors. Further use of the measure would include a workload prioritized metering algorithm. This could reduce the coordination and time required by TMCs to generate a time-based metering plan that is acceptable to all parties.

The need for a workload measure to be included in the process of planning time-based metering parameters will be evaluated in interviews with subject matter experts. The results will be reported in the final version of this document.

Adaptive Scheduling

Adaptive Scheduling refers to rescheduling unfrozen flights to correct for unplanned events. As described previously in the discussion of TRACON Overload and Excess TRACON Capacity, minor changes in the arrival flow environment can result in one of these conditions. When these conditions occur in a gradual build-up, it may be possible for TMA scheduling to automatically adapt to the situation.

In the case of TRACON Overload, the TMA scheduling capability would add empty slots between the last frozen flight and the first unfrozen flight. This gap after the last frozen flight would then reduce the saturation of the TRACON once the empty slot reaches the TRACON.

In the case of Excess TRACON Capacity, the TMA scheduling capability would move the assigned meter fix time of unfrozen flights earlier to increase the demand on the TRACON. Once the flights that are assigned earlier meter fix times enter the TRACON, the demand will be increased.

Both of these effects would be quite easy to implement. And it is even quite easy to determine the exact size of the necessary empty slot or amount to move up the meter fix time. The appropriate method to implement this adaptive scheduling is to reschedule unfrozen flights with respect to the schedule that *would* result if all frozen flights were rescheduled. By rescheduling frozen flights, we automatically re-plan the appropriate amount of TRACON delay and implement that amount of TRACON delay in the assigned meter fix times. By rescheduling unfrozen flights according to the appropriate level of planned TRACON delay, we directly determine the appropriate meter fix times to return to the correct planned TRACON delay level.

McTMA 'What'If' Scheduling

We expect that the negotiation of scheduling parameters between ARTCC TMCs may benefit from providing the ability to each TMC to conduct a 'what-if' schedule evaluation. This allows each TMC to evaluate the workload and efficiency of multiple scheduling alternatives, without presenting those alternatives to the other TMCs until they have been fully developed and evaluated.

5.2. System Architecture Changes

The previous section describes specific TMA algorithm changes and issues. However, to satisfy the McTMA system requirements as identified in Section 4.1, TMA System Requirements, on page 18, additional system changes will be required. These system changes address the distribution of processing, responsibility for maintaining flight databases and computation of ETAs for flights. All of these proposed architectures can be used to implement dependent scheduling between flows from different ARTCC facilities to the same primary airport. However, each architecture uses a different division of processing responsibility.

DESIGN SUGGESTION 1 - Virtual Single Center

The first proposed architecture utilizes a single airspace database for each primary airport (or set of dependent primary airports). In this architecture, CTAS adaptation is used to mimic a single Center for the entire airspace covered by all Centers within a 200 nm radius of the primary airport. To receive flight plan and track data, it is necessary to merge the data feeds from the individual Center facilities into a single data feed.

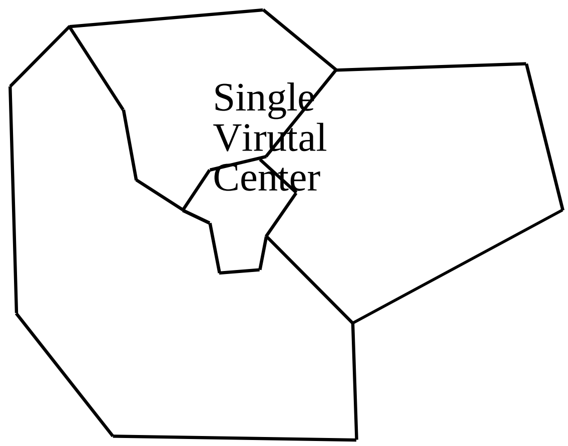

Figure 4 The extended single CTAS architecture minimizes CTAS modifications, but may not support required operational concepts.

The adaptation data for the Single virtual Center allows the Route Analyzer (RA) to compute flight ETAs all the way to the runway threshold, even if Center boundaries are crossed along the flight's route. The Dynamic Planner (DP) receives all flights ETAs at the runway and meter fix, and schedules the flights in the same manner as a true single Center operation.

To allow this architecture to successfully handle the interdependence of flows in congested airspace, the TGUI and PGUI in a given facility are actually connected to all CTAS systems that operate in that facility. For example, in New York ARTCC, there is a separate Virtual Single Center CTAS system for the New York airports, one for PHL, and one for BOS. The TGUI and PGUI in New York ARTCC would display information from each of these CTAS systems that is generating trajectories for aircraft that will enter the facility airspace boundaries. This addition will be necessary to allow traffic management decisions to be made in consideration of the interactions between multiple aircraft flows and ATM jurisdictions. Note that this change only allows the flows that are dependent on each other to be displayed. The computational units (RA, DP, etc.) are not connected and can't support computational functionality to address the dependency of flows.

DESIGN SUGGESTION 2 - Controlling ARTCC

Another way to minimize the changes required to the current CTAS architecture is to continue the single database per ARTCC concept and determine the required additional interfaces and logic to handle the general air traffic environment.

In this architecture, the scheduling process for each of the ARTCCs that is feeding a TRACON must be integrated. To accomplish this, there is one controlling CTAS process that integrates the schedules for all feeding ARTCCs. In general, every TRACON has one and only one controlling ARTCC from a CTAS perspective. Any ARTCCs that are computing ETAs for aircraft bound to a TRACON that the ARTCC does not control would send the ETA information to the CTAS system in the controlling ARTCC. The DP in the controlling ARTCC CTAS would create the integrated schedule for all flights arriving at the primary airport and send the STAs back from to the contributing CTAS systems.

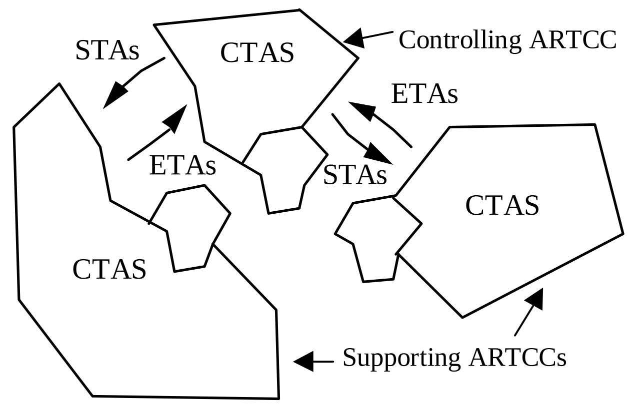

Figure 5 The single database per ARTCC approach would require only moderate changes to CTAS, but would result in some duplicated data.

In this manner, an integrated schedule is generated and each CTAS system can display the tracks, ETAs and STAs for all flights bound for the primary airport. However, each ARTCC's CTAS system must maintain its own duplicate adaptation for the TRACON airspace. This includes detailed ETA generation rules. This may create some challenges in adaptation maintenance.

DESIGN SUGGESTION 3 - Current Facility Model

In the current facility model architecture, the CTAS installation at each facility is responsible for the ETA calculations, scheduling, and advisory generation for that facility only. An important part of the concept is that the responsibility for ETA generation and scheduling does not apply to aircraft that are in the facility's airspace now, but rather, to the operations that are performed on an aircraft that is or will be in the facility's airspace.

In this suggested CTAS architecture, to be modeled after the current facility delineation approach, there would be a separate, single CTAS system at each facility. In the NY area, NY TRACON would have a CTAS system, and NY, Boston, and Washington ARTCCs would each have their own single CTAS system.

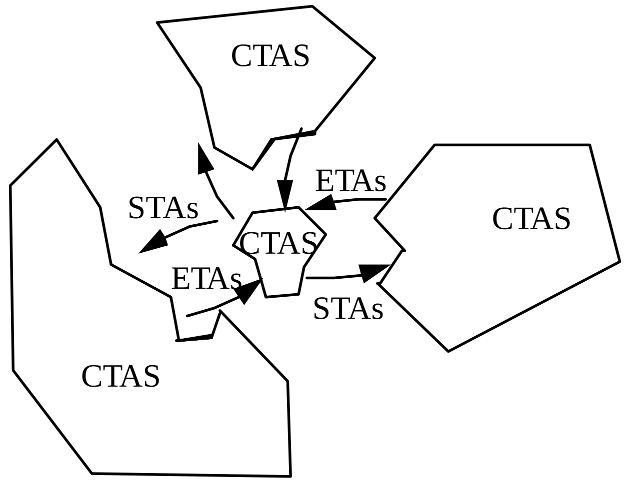

Figure 6 The current facility model architecture would require the most significant changes to CTAS, but would best address new operational concepts for Northeast Corridor operations.

The portion of the ETA for the flight in the ARTCC would be computed by the ARTCC CTAS system. Then the portion of the flight in the TRACON would be computed by the TRACON CTAS system. Once this ETA is available, the TRACON DP can perform the TRACON portion of scheduling. The output of this process is a runway scheduled time, and a new meter fix scheduled time. A message is sent from the CTAS system in the TRACON to the CTAS system in the ARTCC with this new meter fix STA. The ARTCC CTAS system can then perform advisory generation to meet this meter fix time.

Although this architecture requires the most significant changes to the current CTAS architecture, it may best support future changes to address the interdependence of flows and operations in congested airspace.

5.3. Adaptation Changes

The following section provides an overview of adaptation changes that will be required to the TMA system to support McTMA operations. Adaptation changes refers to changes in the type of information that is adaptable in CTAS. Clearly, there will be a significant effort to specify all of the required data content. This section discusses the data format for new types of adaptation information.

Coordinate System

To merge the input track data sources from multiple ARTCCs, McTMA adaptation data must include the Host coordinate system for each of the feeding ARTCCs, and a single separate coordinate system for McTMA operation. All input data that is provided in the native ARTCC Host coordinate system is converted to the single McTMA coordinate system. This McTMA coordinate system uses a point of tangency that is near the center of the combined airspace of all feeding ARTCCs to minimize the error caused by the use of a flat earth model.

Meter Fixes by ARTCC

For many McTMA functions it is necessary for CTAS to know which ARTCC a meter fix is in. This is used by McTMA to limit the actions of TMCs in making entries to the McTMA system, to ensure that TMCs from one ARTCC don't make changes to the scheduling parameters that apply exclusively to the other ARTCC. This data is also used for display of the owning ARTCC for internal departures and on timelines and load graphs, as well as other McTMA capabilities.

Allowable TMA Functions

It is expected that the authority to perform certain TMA functions will be allocated to specific facilities. For example, it may be appropriate for the TRACON TMC to enter future airport configuration changes. However, it may not be appropriate for the TRACON TMC to enter miles-in-trail restrictions. These two examples illustrate the types of decisions that must be made through research and involvement of subject matter experts. We suggest that this research could be conducted more efficiently if the authority to perform TMA functions in each type of facility were controlled through adaptation.

Merged Waypoints and Routes

The waypoint and route tokens in flights plans and ETA generation instructions must be known to CTAS. Dependent on the architecture that is used, either a single merged database of waypoints and routes must be available, or it may be necessary to ensure that the waypoints that are communicated between CTAS systems be commonly understood. As there may be specific implications for the particular architecture that is selected, the specific adaptation requirements for waypoints and routes are yet to be determined.

ETA Generation Rules

Again, the adaptation requirements for ETA generation rules (analysis_categories and category_definitions) are dependent on the architecture that is selected. Under the Virtual Single Center approach, little change is required to ETA generation rules, besides merging the ETA generation rules that would exist for each ARTCC separately into a single set. Under the Controlling ARTCC approach, again little change is required, as ETAs are generated to a meter fix and runway threshold. The integration of ETAs takes place in the DP of the controlling ARTCC CTAS system. However, in the Current Facility Model approach, ETA generation rules change significantly. In this architecture, the CTAS systems that operate in the ARTCCs only compute ETA and trajectories to the meter fix. Then the TRACON CTAS system computes the remainder of the trajectory, to complete the ETA. Thus, each CTAS system must have a different set of ETA generation rules that are appropriate for the airspace in which the CTAS is operating. In addition, adaptation must be designed to ensure that the ETAs that are generated by each CTAS system can be communicated and understood by the adjacent facilities' CTAS systems.

6. Complex Airspace Analyses

This section documents analyses that have been conducted of complex airspace issues that will affect the deployment and operation of the McTMA system. Two analyses are presented here. The first analysis addresses the interaction of flow management initiatives when some initiatives address airport saturation and other initiatives address sector saturation. The second analysis addresses the use of the Tower En-Route Control (TEC) procedures for Philadelphia arrivals.

6.1. Traffic Flow Management Interactions

The coordination between ZNY, ZDC and ZOB often must address en-route airspace saturation and dependencies between traffic flows, in addition to terminal area arrival constraints. It is rare that the terminal area arrival constraint is the only consideration in traffic management initiatives.

This inter-facility coordination makes use of the entire FAA operational structure, including Controllers, Supervisors and Traffic Managers. The Supervisors play a critical role in planning and managing sector workload with respect to crossing streams of traffic and downstream traffic management constraints.

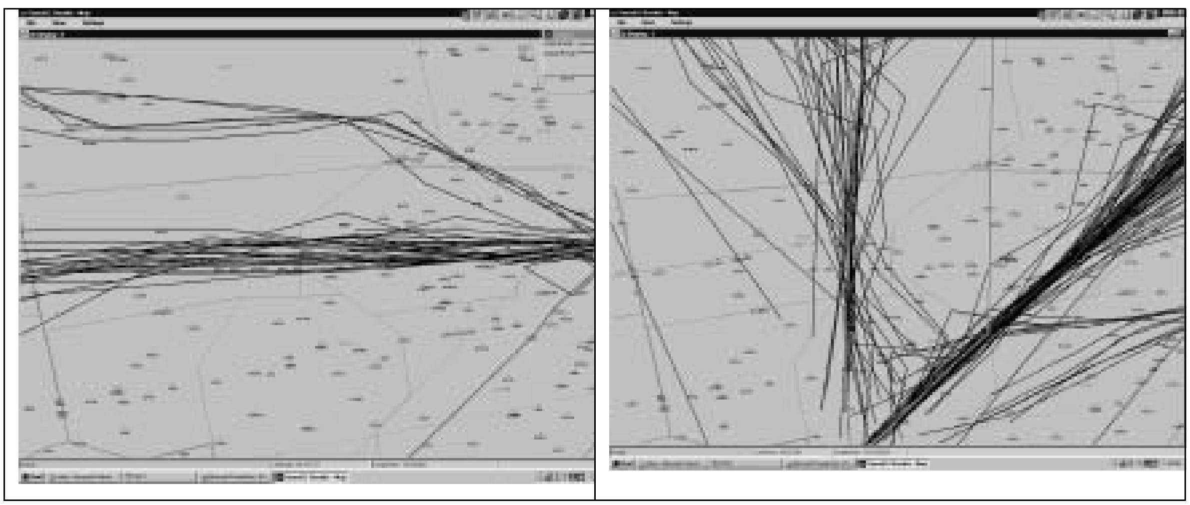

Figure 7 Dependency between IAD and PHL flows in ZNY sectors 26 and 27

As an example of the traffic management initiatives that occur in complex airspace, consider the ZNY Middletown sector (27). The Middletown sector receives handoff of PHL arrivals from the ZOB Imperial sector at FL250. Flights descend to FL170-180 by the time they reach 30 miles west of Harrisburg (HAR) for handoff to ZNY sector 26. Descending the traffic crossing the ZOB boundary is often complicated by the speed of the aircraft at that altitude, which can exceed 500 knots. Thus, the aircraft need not only to descend, but also to reduce their speed drastically. Consequently, operations in this sector typically result in compressed traffic flows.

As shown in Figure 7, sectors 27 and 26 in ZNY handle arrivals to both Washington Dulles (IAD) and Philadelphia (PHL) airports. Thus, there are crossing streams of traffic that are dependent on each other. The IAD arrival stream becomes sufficiently complex in these sectors that miles-in-trail (MIT) restrictions are placed on PHL arrivals to reduce the overall sector demand. There are interactions of some flows that are not based on MIT restrictions. When some sectors have to hold or significantly delay certain flows, other flows may be blocked. This is an important part of the grid-lock equation.

Figure 8, below, shows the percentage of traffic in sectors 26 and 27 that are destined for IAD, PHL or other airports by hour of day.

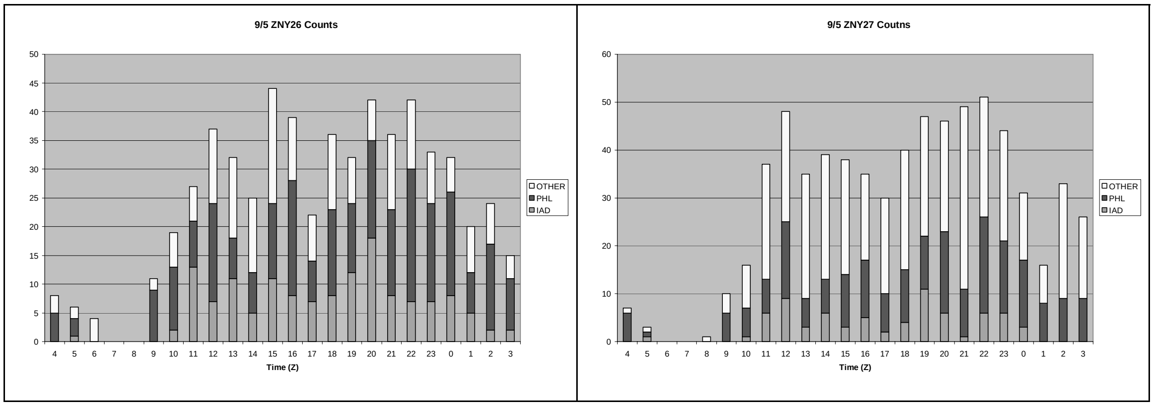

Figure 8 IAD and PHL Traffic Flow through ZNY Sectors 26 and 27

For an ATM DST to accurately manage these traffic flows, these miles-in-trail and other restrictions must be explicitly modeled. In general, in complex airspace, the Traffic Flow Management goals are not limited to managing airport arrival capacity alone. TFM initiatives are also used to manage sector demand and workload. All of these TFM goals must be handled by any tool that intends to provide automated TFM support in complex airspace.

Currently, the operational tools that are used to support complex airspace TFM are miles-in-trail restrictions without any technology to predict the effect of the restrictions. Ideally, McTMA could provide such prediction capabilities. Figure 9, below, shows that there are significant differences in the flight times experienced by flights transiting sector 26. Correlation between the traffic volume and the flight times can be seen. This demonstrates the need to model the impact of congestion and constraints to accurately predict the resultant downstream flow.

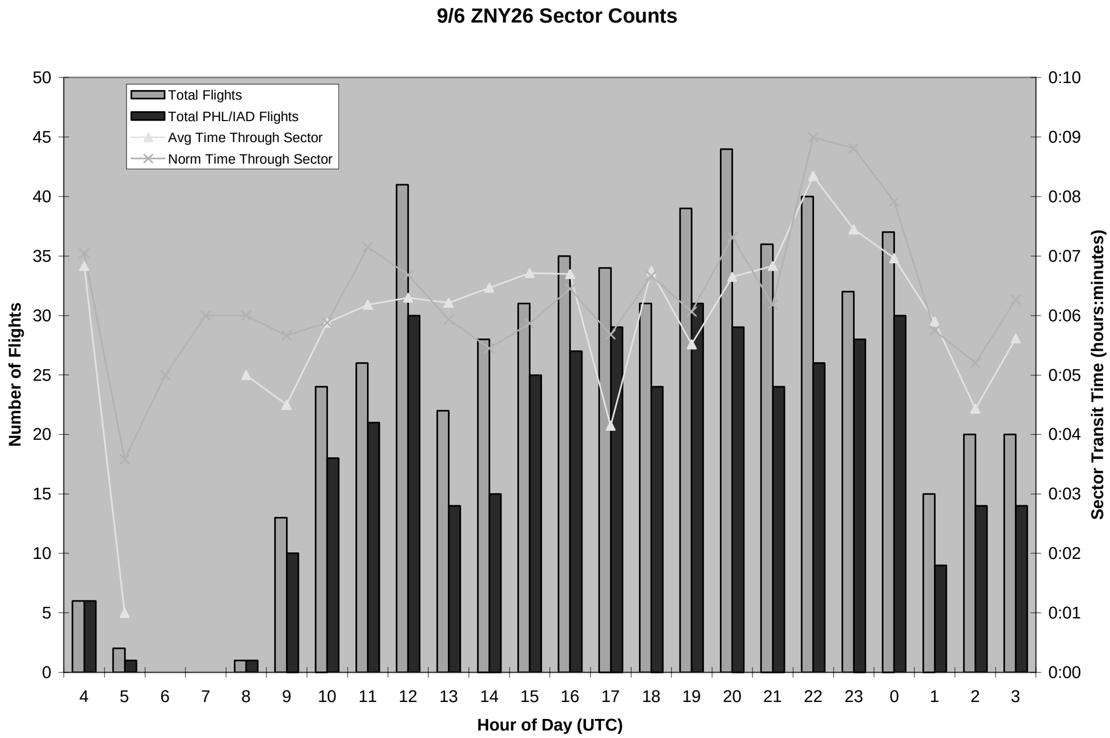

Figure 9 Flight Time in ZNY sector 26 compared to Traffic Flow

In this figure, the count of total flights in ZNY sector 26 is shown in the left column in each hour. The right column shows the count of arrivals to PHL or IAD. The line graph shows the average transit time of all flights in ZNY sector 26 during the corresponding hour of the day. The yellow line with triangular markers shows the average transit time for the flights in sector 26 on September 6, whereas the blue line shows the average transit time averaged over a thirty day period. The variability in the transit time of the sector can be used as a measure of the potential error in ETA prediction of flights if the factors that cause this variation are not modeled. This analysis does not provide complete detail of the causal factors. Some of the factors are the differences in demand patterns and flight routes from hour to hour, and the differences in aircraft types. Other causal factors include the use of miles-in-trail restrictions. However, this initial analysis indicates that the resultant ETA error could be as much as one or two minutes if some of these causal factors are not modeled.

6.2. Tower En-Route Control (TEC) Procedures for PHL Arrivals

Tower En-Route Control (TEC) procedures allow flights to fly from departure airport to destination without entering ARTCC airspace. In some cases, this may allow a more direct route than would be other wise possible.

However, for the application of McTMA, the use of the TEC procedure can cause problems. When flights use the TEC procedure, they are not tracked by an ARTCC Host computer. Thus, the McTMA system may not have the necessary data about the flight to schedule a slot for the flight at the airport.

If McTMA assigns slots to non-TEC flights to fill the available arrival rate, and then additional flights arrive through the use of the TEC procedure, demand will exceed capacity. Thus, it is essential to quantify the potential impact of the TEC procedure.

A complicating factor in such an assessment is the fact that some flights may not use the TEC procedure, but may enter PHL approach control from an adjacent approach control facility. Philadelphia approach control airspace is surround by a number of other approach controls including Atlantic City, Dover, Reading, Newark (part of N90), Baltimore-Washington, and others. It is not uncommon for flights in an ARTCC sector to request a lower altitude that puts them in another approach control's airspace. In such situations, McTMA reserves a slot for the flight, because the data was available from the Host computer. However, the flight is not under the control of an ARTCC sector when it crosses the meter fix into the PHL approach control. Thus, McTMA metering may be further complicated.

There are three different cases to consider in evaluating use of the TEC procedure:

1. Pure TEC: Flights that never entered an ARTCC sector. Track data for these flights is probably not available from the ARTCC Host computer. Flight Plan data may be available from the Host computer for these flights
2. Adj Apch: Flights that entered PHL from an Adjacent Approach Control but were in an ARTCC sector at some point in their flight. Track data is available for such flights when they are in ARTCC sectors. Flight Plan data is available for such flights from the Host.
3. ARTCC Entry: Flights that entered PHL from a ARTCC sector. Flight Plan and Track data is available from the Host.

Through the use of the Post-Operations Evaluation Tool (POET), which maintains a database of Enhanced Traffic Management System (ETMS) data, we analyzed PHL arrival flights to determine the percentage of flights that fall into each of these categories. Although track data may not be available on TEC flights from the Host computer, the ETMS system collects real-time track information from all Host computers as well as most of the Approach Control facilities around the country.

Using POET, we evaluated each track hit for all of the PHL arrival flights over a one week period to determine whether the track hit was in a sector or an approach control facility. Using this information, we determined whether or not the flight never entered an ARTCC sector (Pure TEC), entered an ARTCC sector and another approach control before PHL (Adj Apch), or entered PHL approach control directly from an ARTCC sector (ARTCC Entry).

The percentage of PHL arrivals that fall into each of the 3 TEC categories are shown in Figure 10, below.

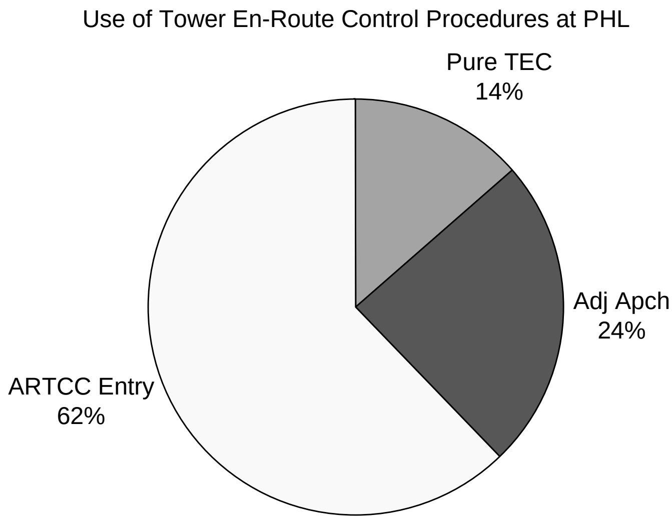

Figure 10 Use of the Tower En-Route Control Procedure for PHL Arrivals

Dependent on the characteristics of the airspace and routes surrounding the PHL terminal environment, flights arriving through different PHL arrival fixes will use the TEC procedure to a different degree. This is shown below in Figure 11, below.

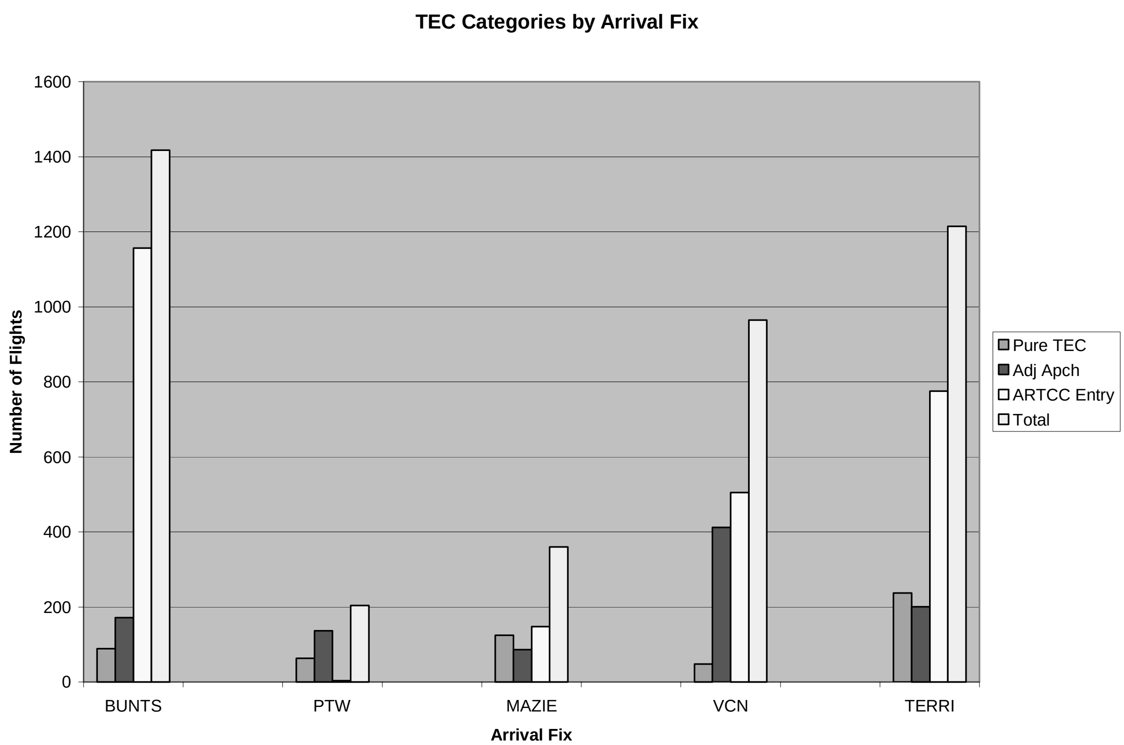

Figure 11 TEC Characteristics by Arrival Fix

The following figures provide additional detail regarding the use of TEC procedures for PHL arrivals. For each arrival fix, two pie charts are shown. The first pie chart shows the percentage of flights in each of the 3 TEC categories that arrived through the corresponding arrival fix. The second pie chart shows the departure airport of Pure TEC flights through that arrival fix. This information is provided to characterize the use of TEC procedures, and to provide suggestions regarding the design of scenarios for McTMA simulations.

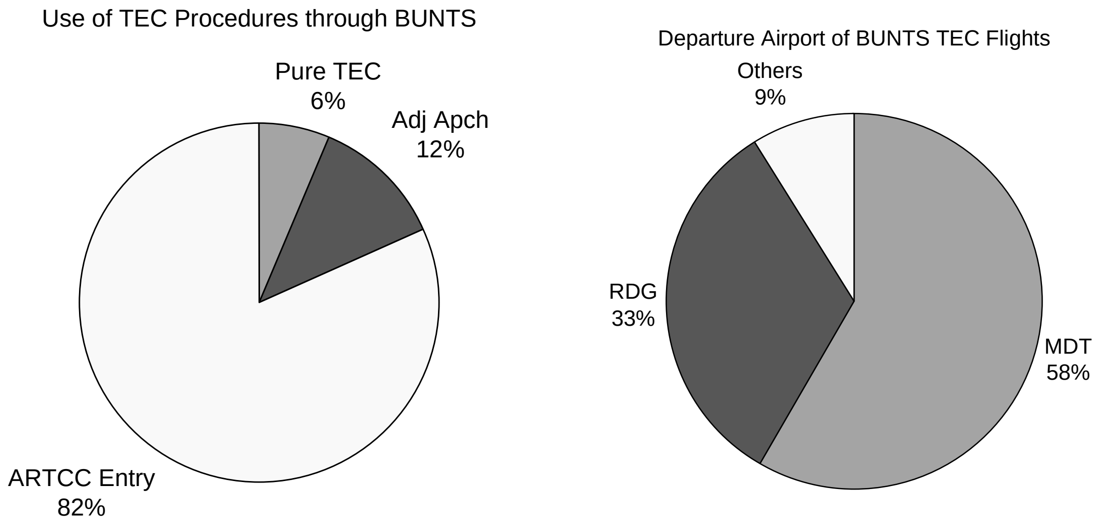

Figure 12 TEC Characteristics for BUNTS

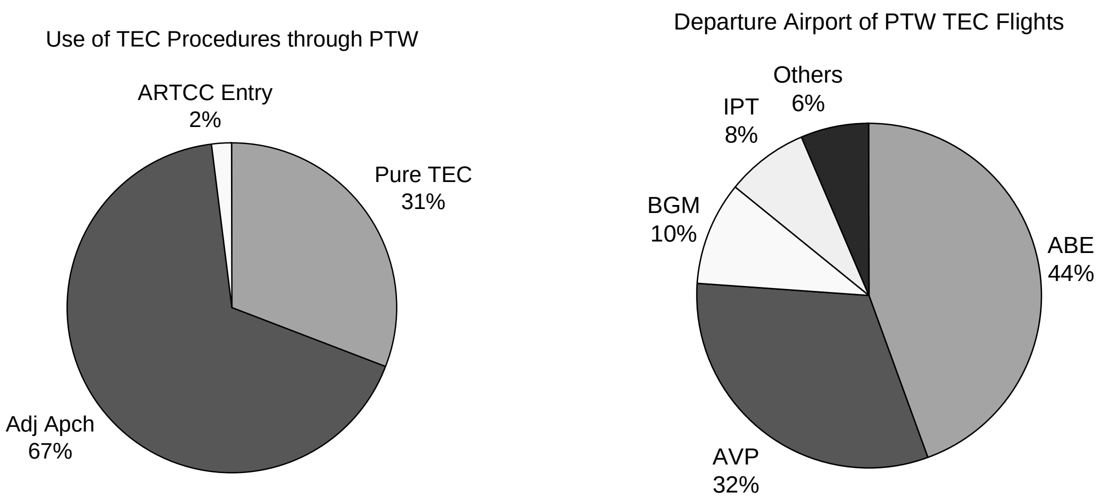

Figure 13 TEC Characteristics for PTW

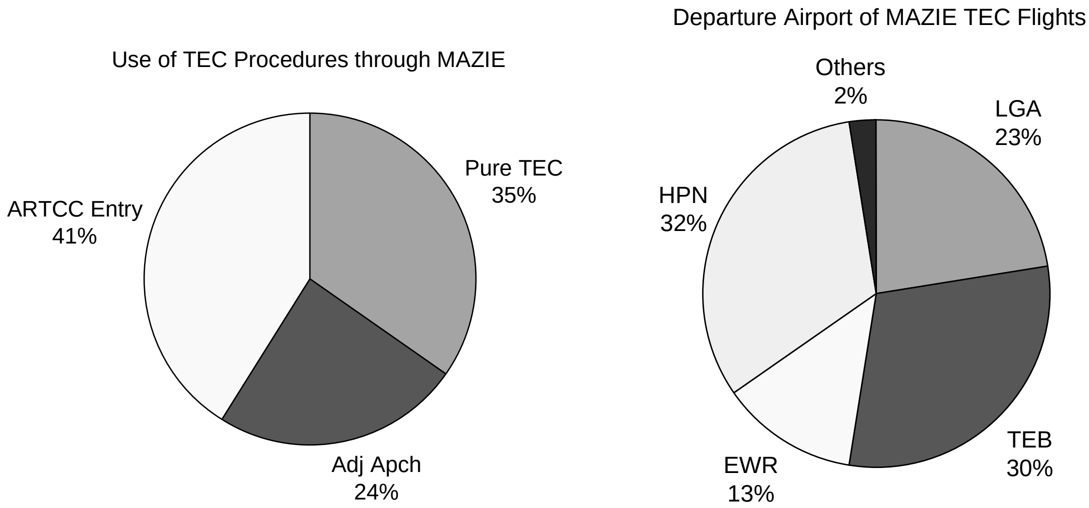

Figure 14 TEC Characteristics for MAZIE

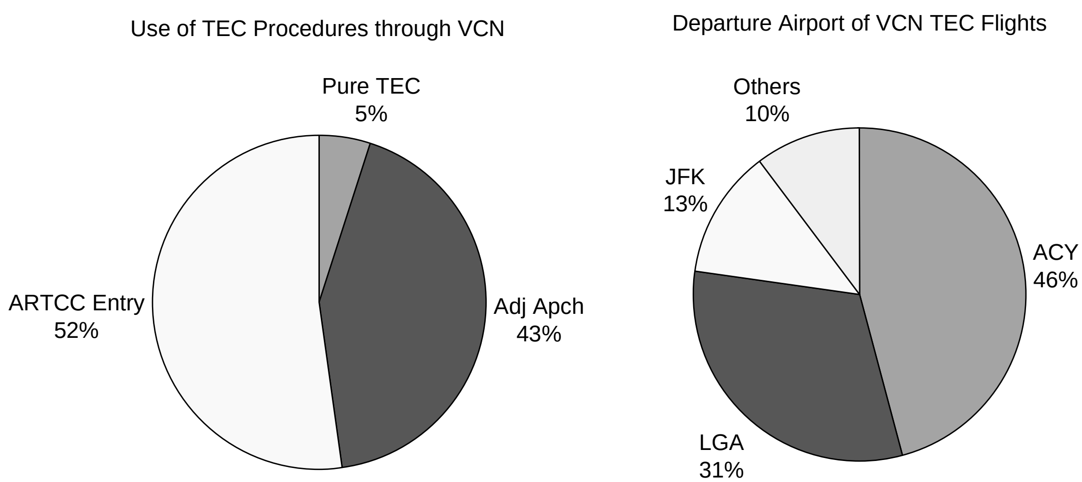

Figure 15 TEC Characteristics for VCN

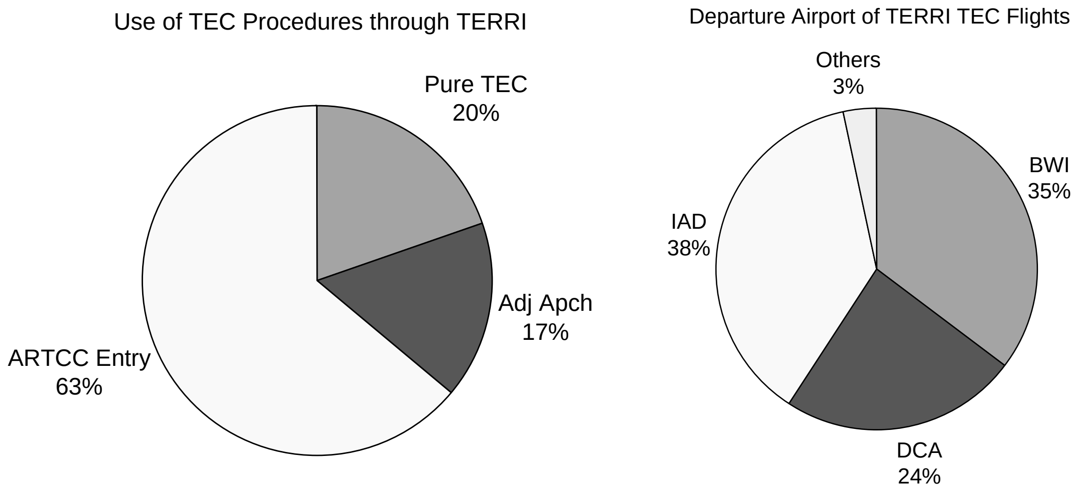

Figure 16 TEC Characteristics for TERRI

7. Conclusions

The airspace and procedural characteristics of complex airspace differ significantly from the characteristics of most of the current single center TMA deployment sites. These differences will affect the ability of McTMA to provide the expected and required capabilities in the new complex airspace environment.

In addition to providing the capability to meter arrival flights to a single primary airport, McTMA must also support the Traffic Management Specialists and Supervisors in evaluating and managing the interaction of air traffic flows.

An operational concept has been presented in this document that focuses primarily on the use of McTMA for arrival metering to a primary airport. Additional research and simulation is required to fully identify the opportunities for complex airspace efficiency improvements available to McTMA.